X-raying Weak-Line Quasars:

Implications for Accretion Flows, Winds, and BLRs

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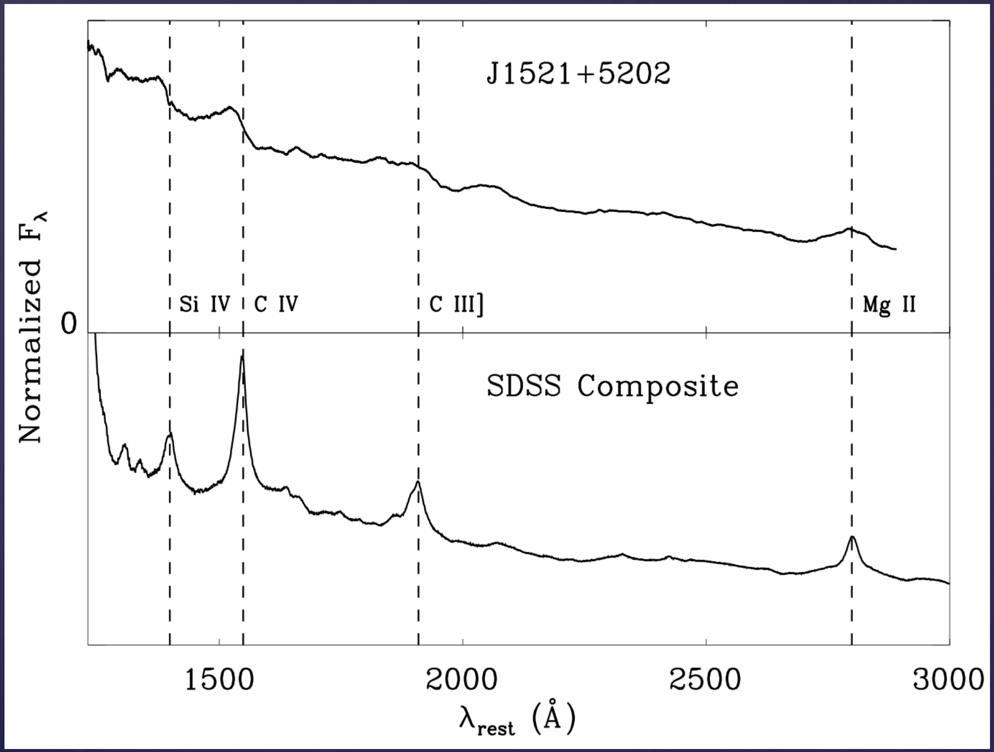
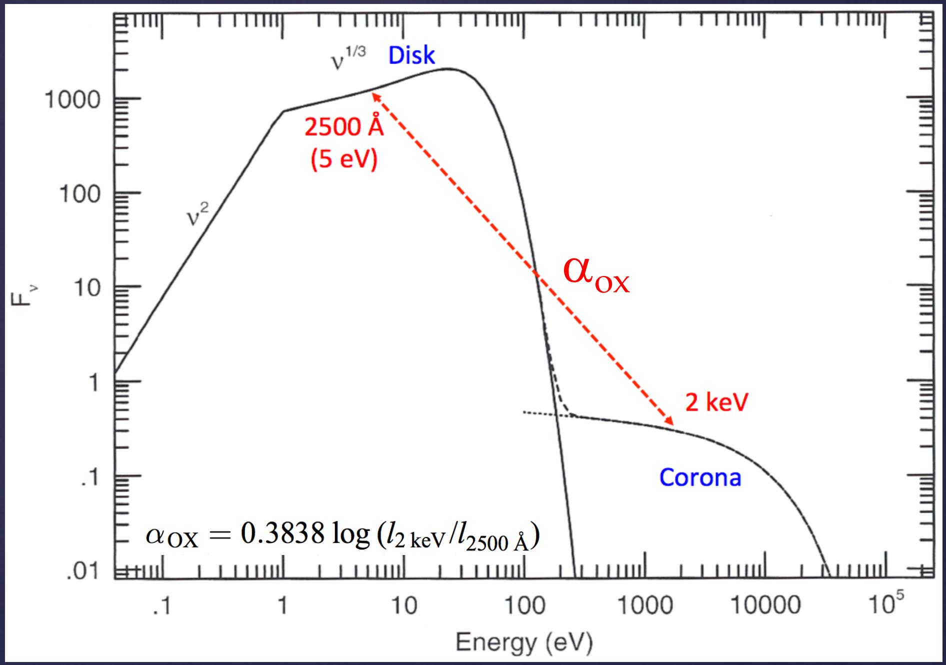
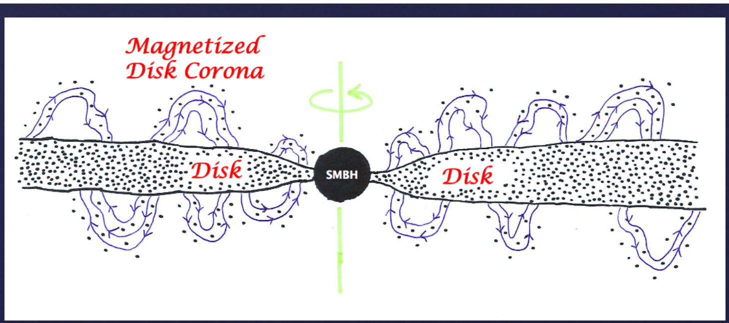
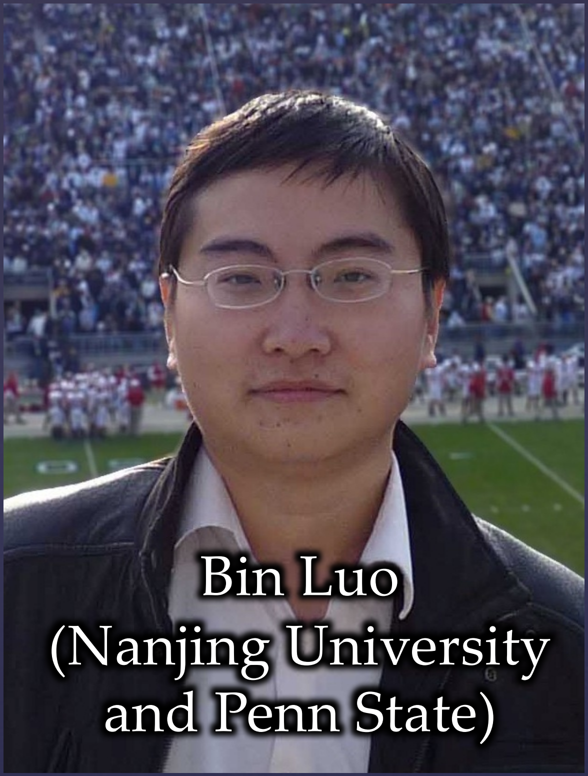






Main Collaborators



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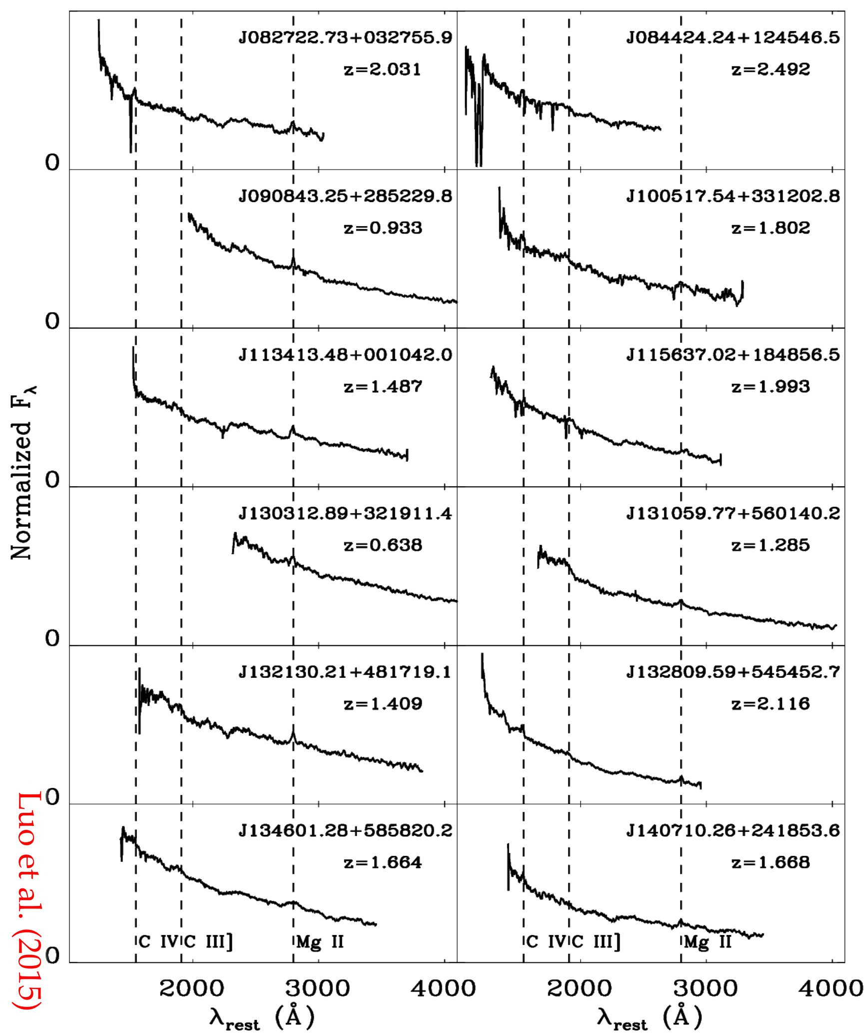
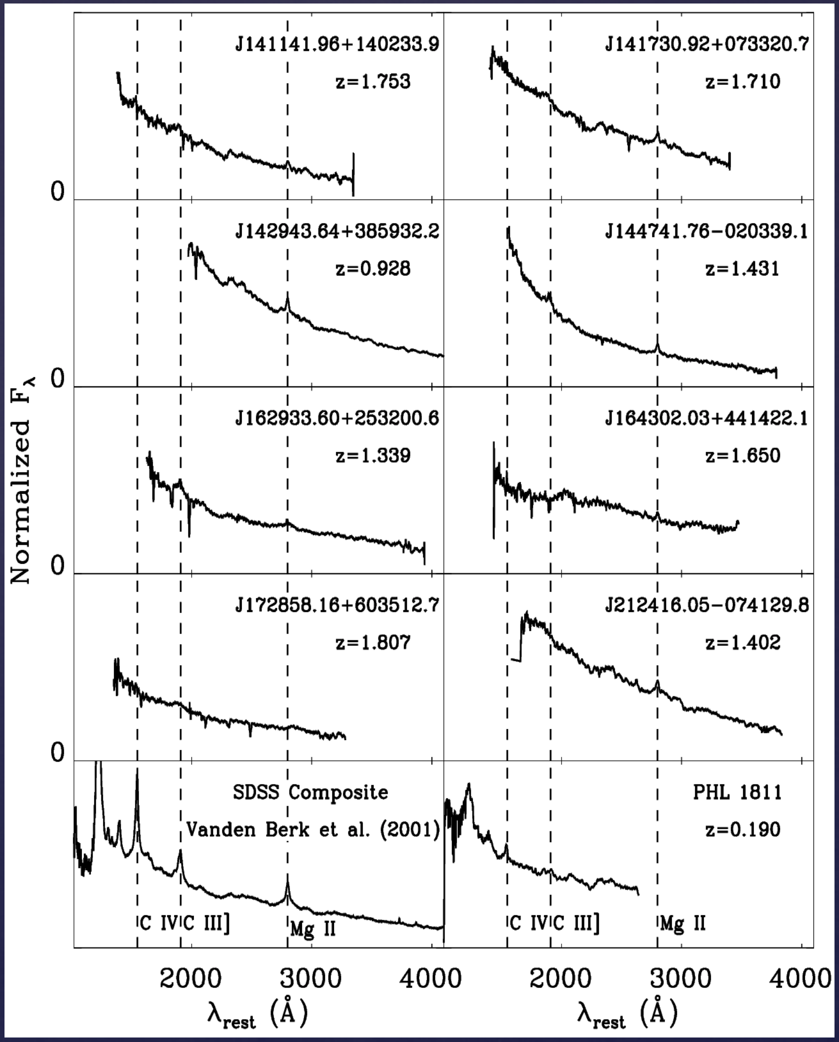
See Luo et al. (2015, ApJ, 805, 122) for most recent details.

SDSS Has Found ~ 400 Weak-Line Quasars (WLQs)



Luo et al. (2015)



Radio-quiet, blue, luminous, type 1 quasars.

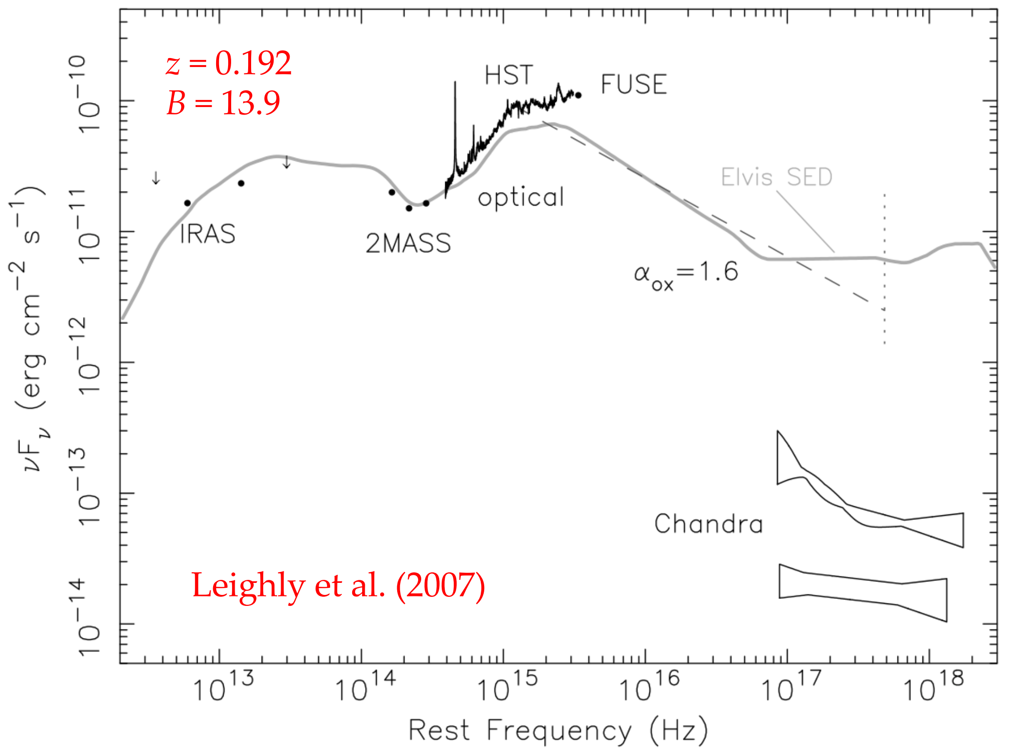
Multiwavelength and multi-epoch studies indicate not BL Lacs, not line obscuration, etc.

Prior to our work, limited X-ray coverage.

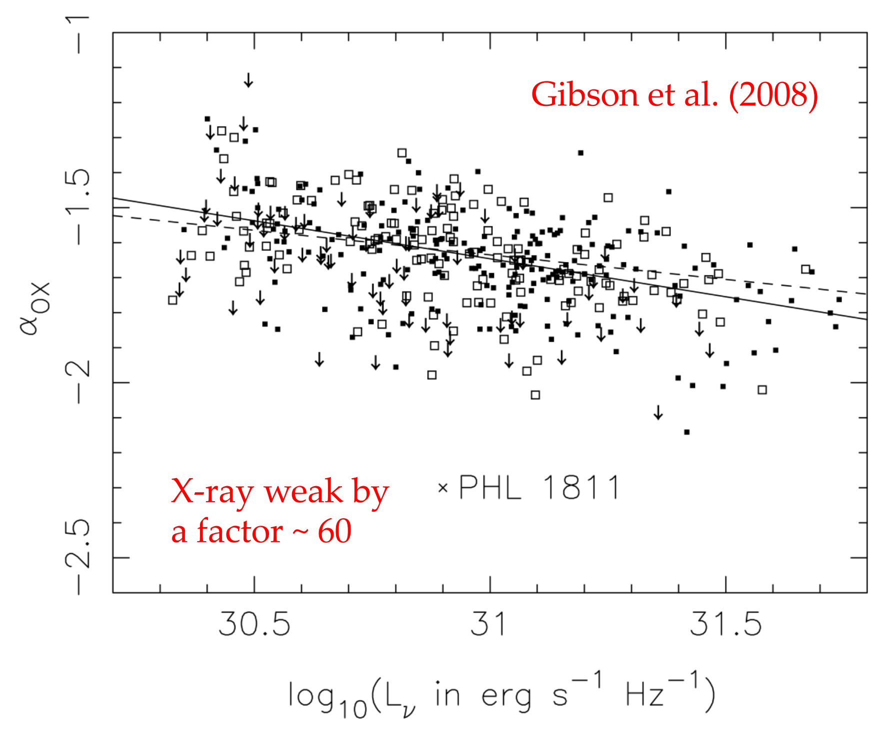
2-3 of them appeared to be notably X-ray weak, though a couple others were not.

An X-ray Weak WLQ: PHL 1811

Broad-Band SED of PHL 1811



Outlier from Luminosity-α_{ox} Relation



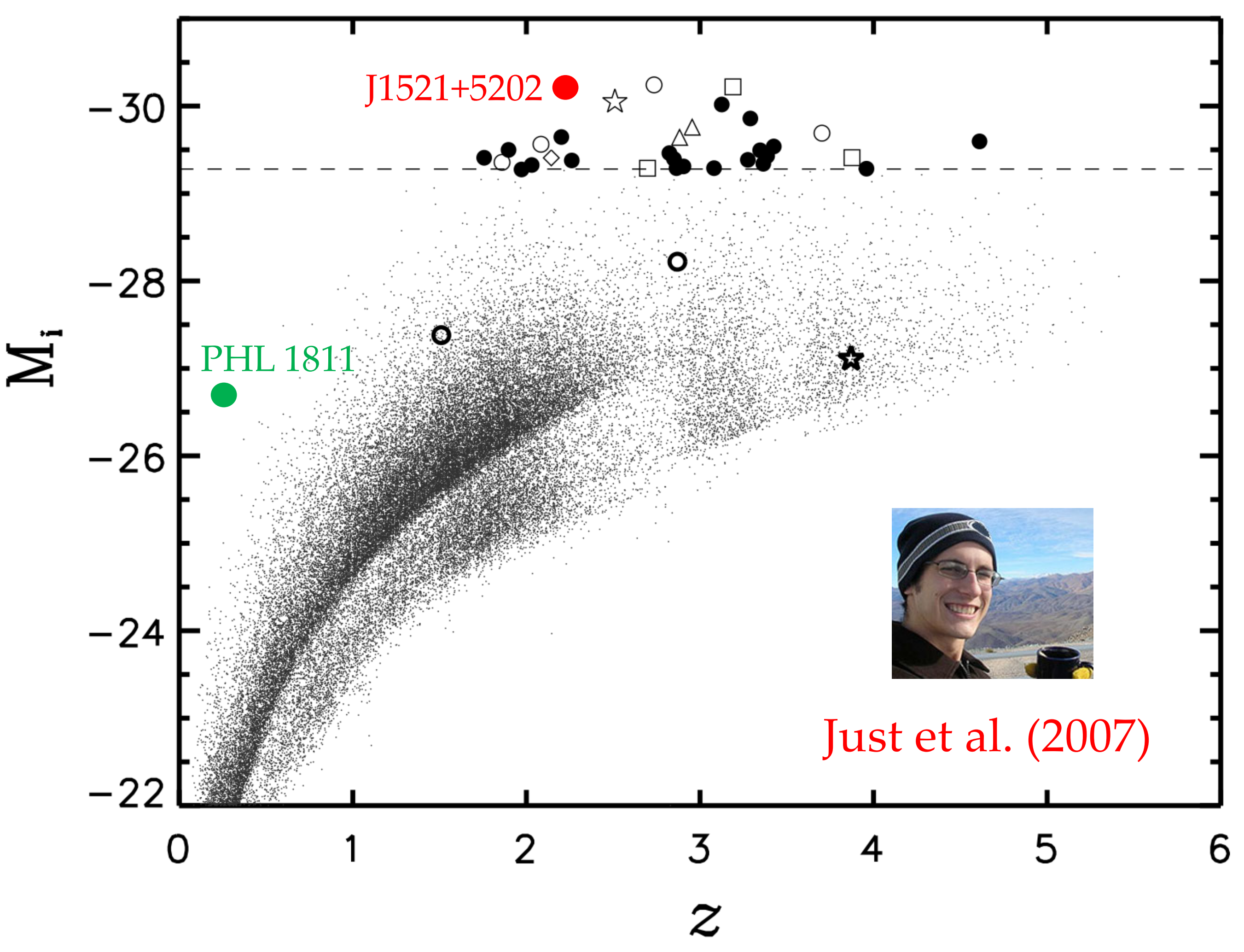
Has an X-ray weak spectral energy distribution (SED).

No apparent X-ray absorption. No UV BALs or mini-BALs. X-ray variability.

At least some of the emission-line properties can be explained by unusual SED – weak high-ionization lines, strong Fe II, III in NUV.

PHL 1811's Big Brother

Luminosity vs. Redshift for SDSS Quasars



About 25 times more optically luminous than PHL 1811.

$M_i = -30.2$.

Only 3 counts in 4 ks Chandra snapshot.

X-ray weak by a factor of ~ 35.

UV/opt spectrum like that of PHL 1811.

Chandra Targeting of WLQs

We have now targeted 51 WLQs in Chandra exploratory snapshot observations:

33 general WLQs at $z \sim 0.5$-2.5 that are optically bright ($i < 18.6$).

Mostly from the Plotkin et al. (2010) sample with REW < 5 Å for all measurable emission features.

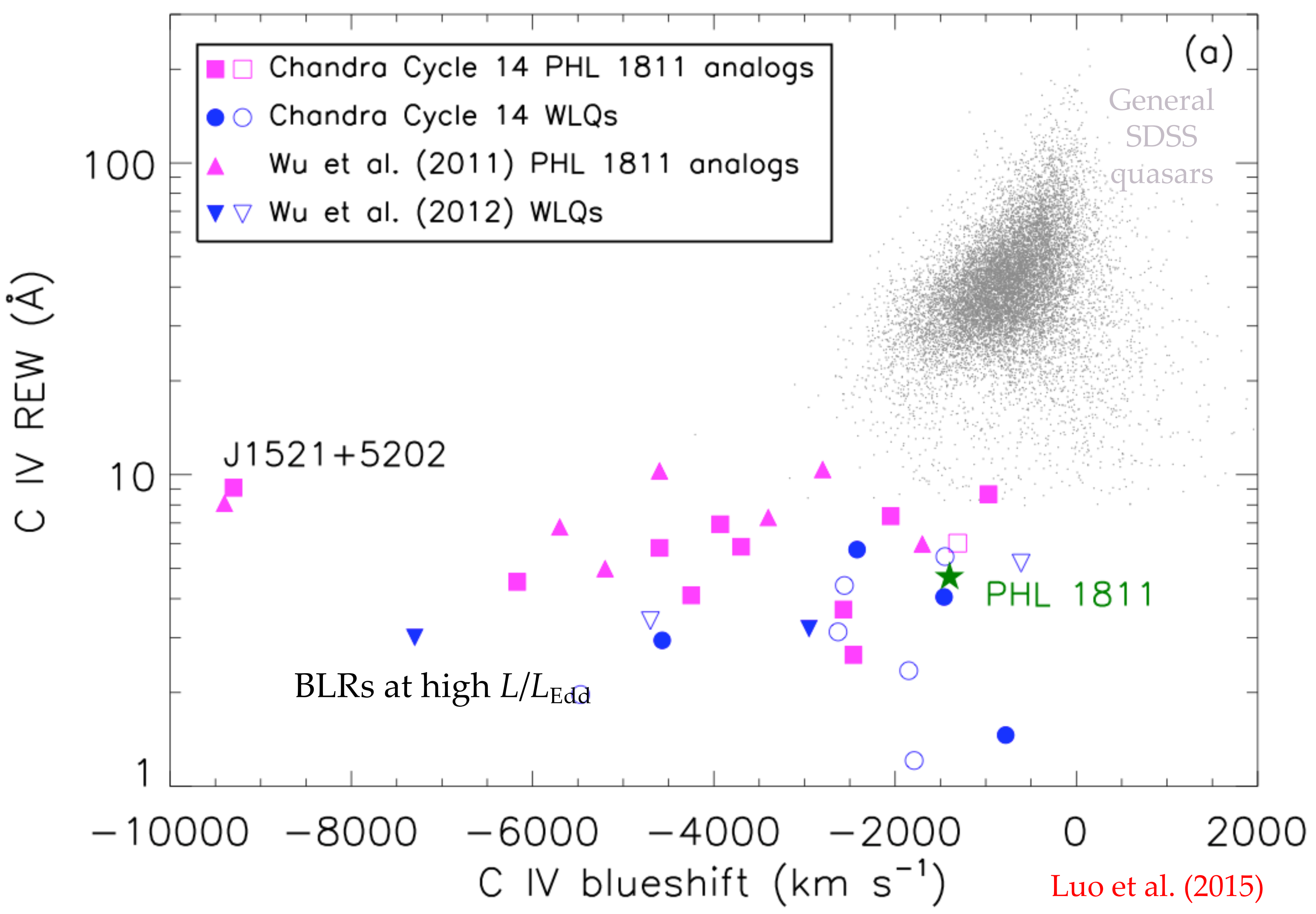
18 "analogs" of PHL 1811 at $z \sim 1.7$-3 that are optically bright ($r < 18.9$).

Additionally have strong UV Fe II/Fe III and large C IV blueshifts.

Avoided targeting objects with BALs or mini-BALs, since we wanted simple "clean" systems - without additional complexity from UV/X-ray absorption.

Also a 40 ks Chandra observation of the extremely luminous J1521+5202 ("big brother") aimed at obtaining basic X-ray spectral data.

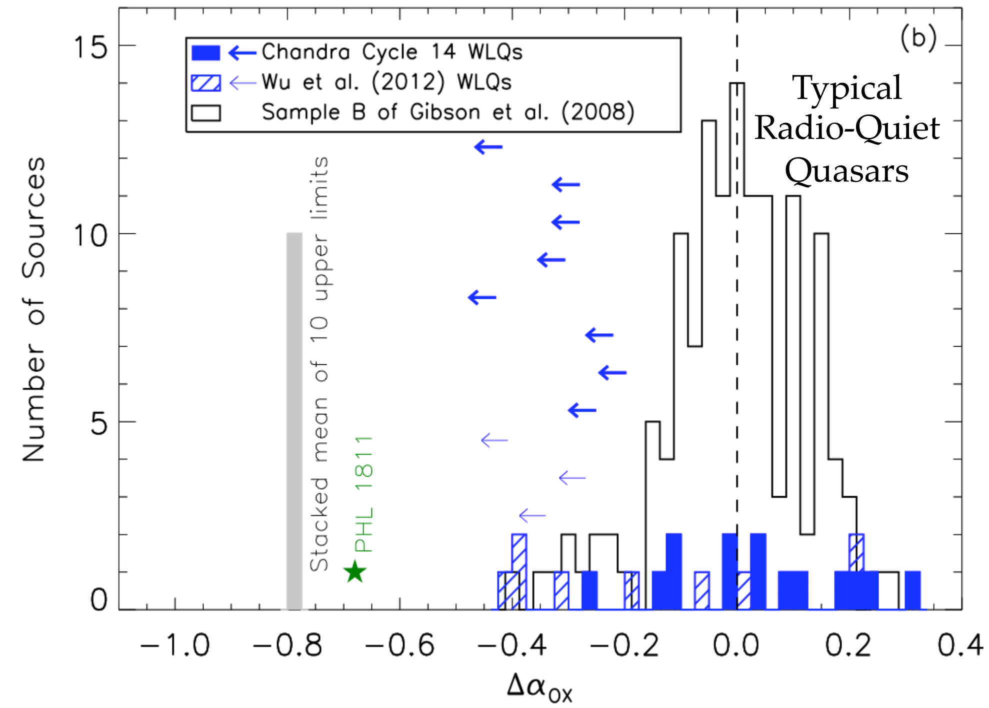
C IV Rest EW vs. Blueshift



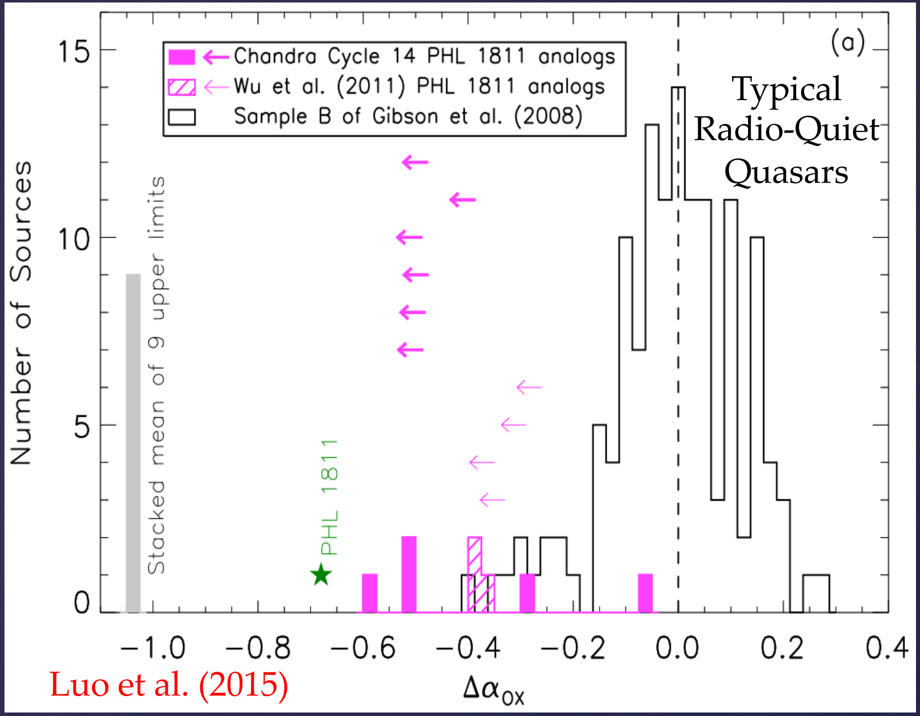
Luo et al. (2015)

Many Are Strikingly X-ray Weak!

General WLQs – 16/33 X-ray weak



Analogs of PHL 1811 – 17/18 X-ray weak



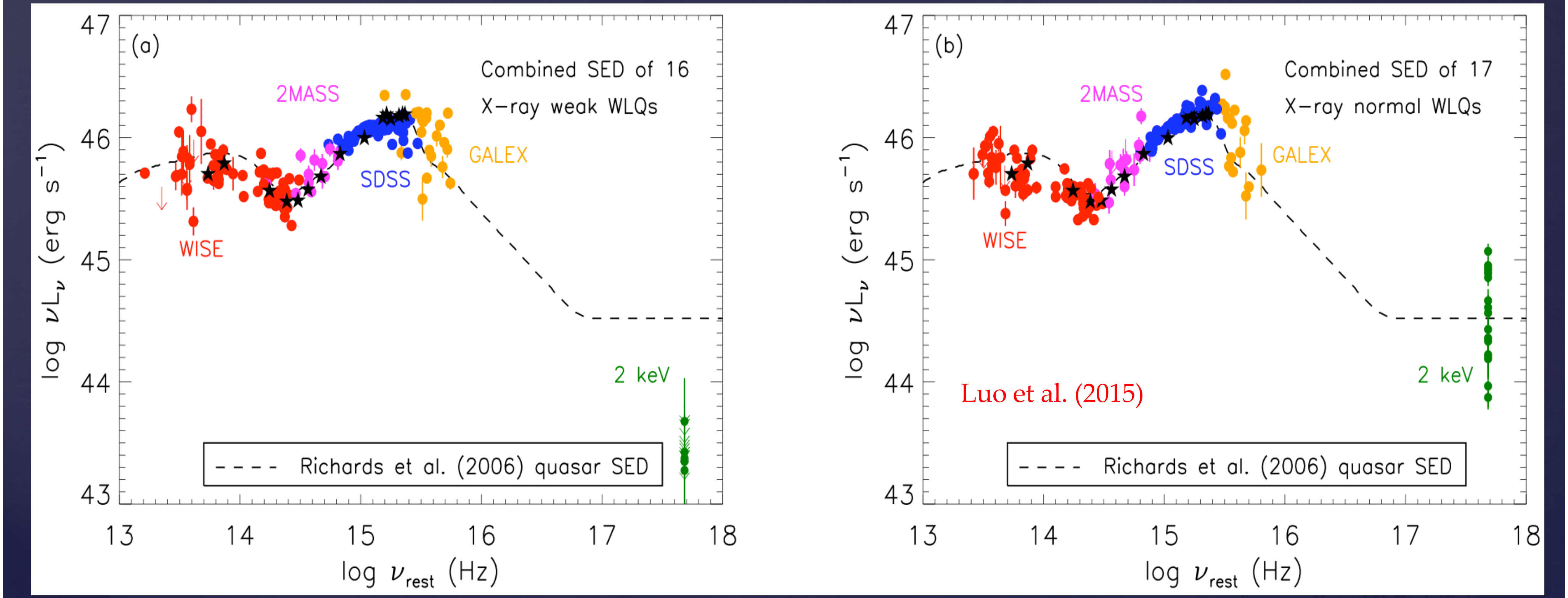
Luo et al. (2015)

Stacking of the X-ray weak WLQs shows factor ~ 17 X-ray weakness ($\Delta\alpha_{ox}$ = -0.47).

Stacking of the X-ray weak 1811s shows factor ~ 39 X-ray weakness ($\Delta\alpha_{ox}$ = -0.61).

Unusual “soft” SED reaching BLR likely driving the weak lines.

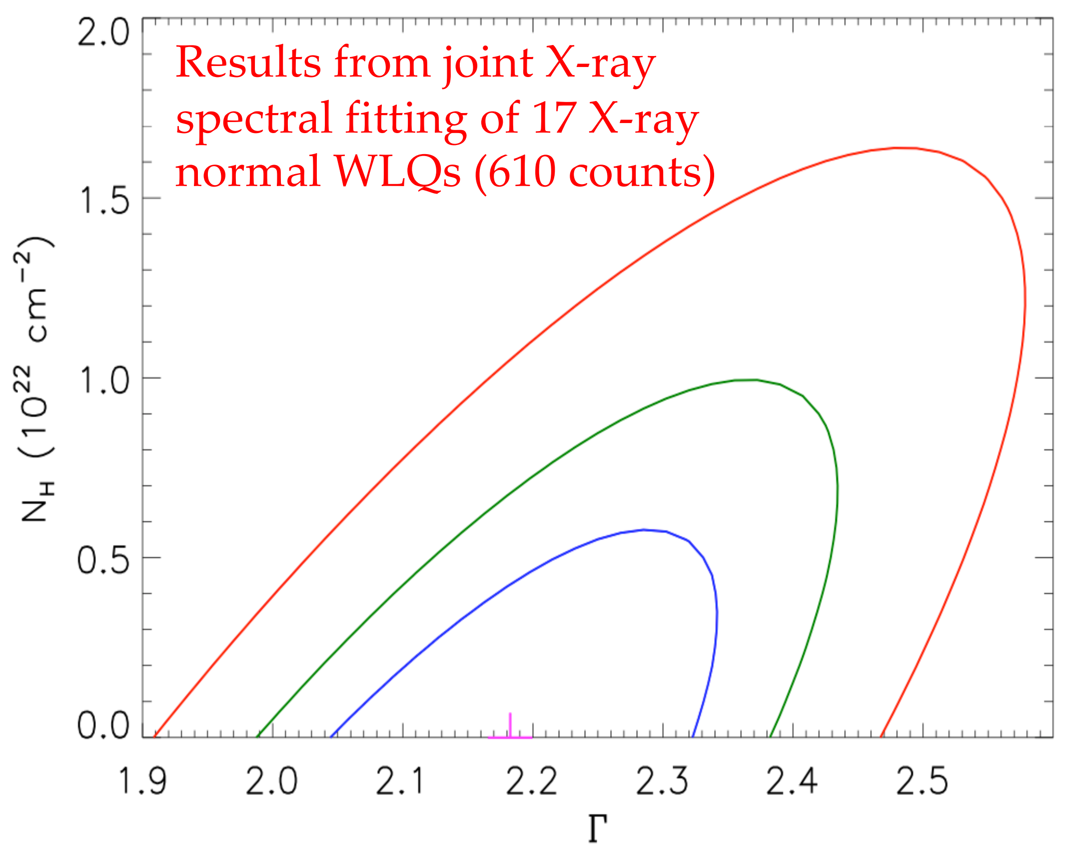
Broad-Band Spectral Energy Distributions

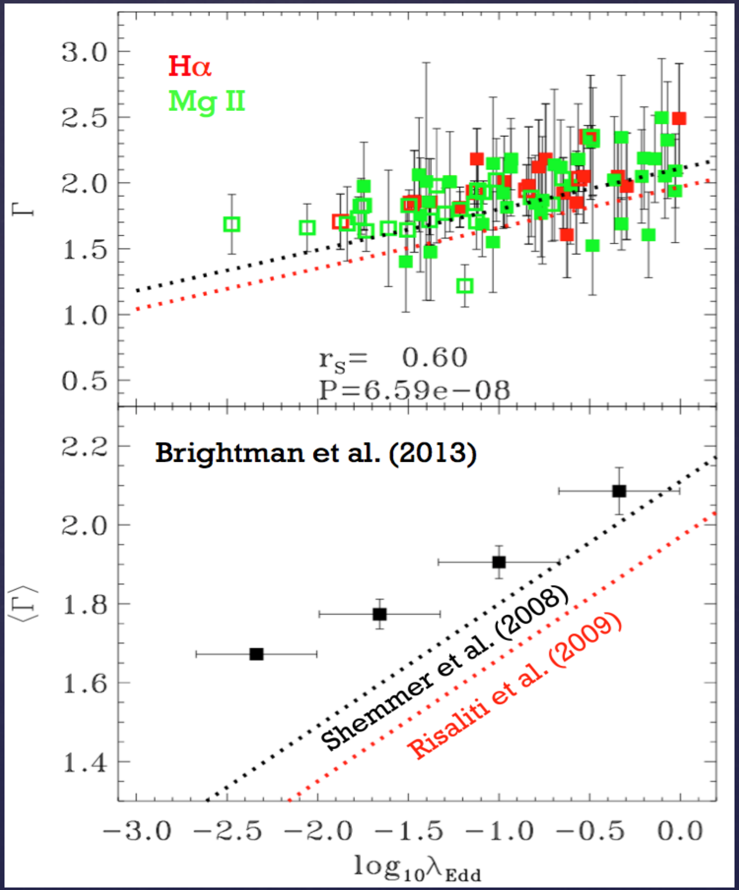


Luo et al. (2015)

IR-to-UV continuum SEDs appear nominal.

Basic X-ray Spectra: X-ray Normal Objects

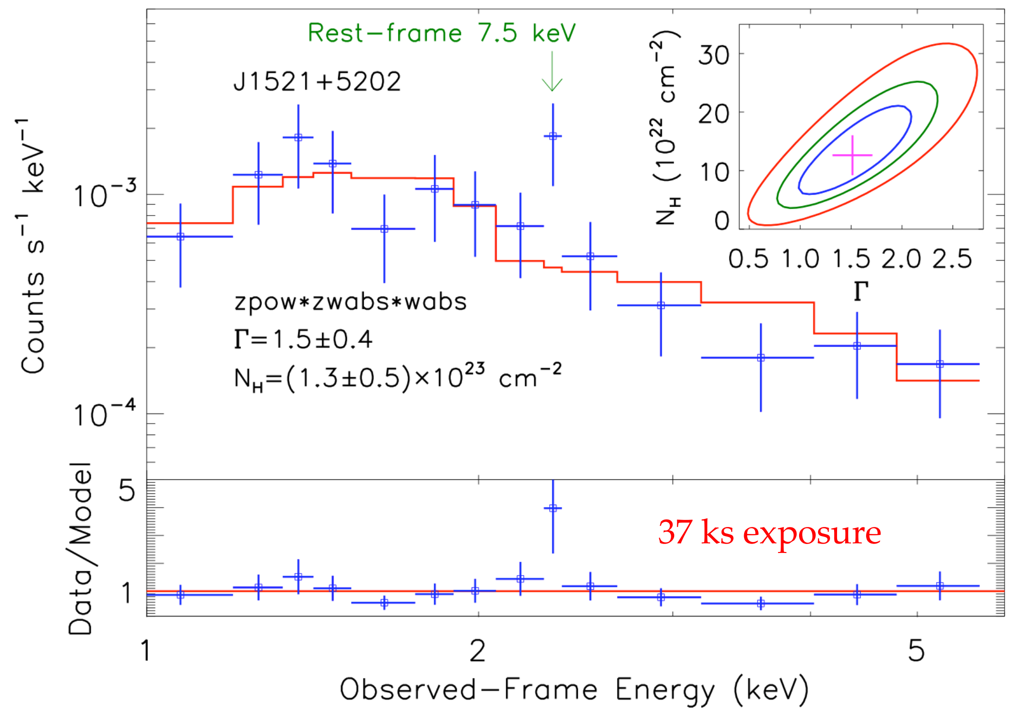

Results from joint X-ray spectral fitting of 17 X-ray normal WLQs (610 counts)



Joint spectral fitting shows steep power-law X-ray spectra, on average, with Γ = 2.18 +/- 0.09. Suggests a high Eddington fraction with $L/L_{\rm Edd} \approx 1$+.

Basic X-ray Spectra: X-ray Weak Objects

Chandra Spectrum of SDSS J1521+5202



Hard to get X-ray spectral properties for the X-ray weak objects!

One exception is the extraordinarily luminous SDSS J1521+5202.

It has a very hard spectrum with $\Gamma_{\mathrm{Eff}} = 0.6 +/- 0.2$.

Suggests heavy X-ray absorption, and/or Compton reflection.

Fitting indicates $N_H \sim 10^{23}$ cm^{-2}, and perhaps much greater.

Stacking of the other X-ray weak objects also indicates a hard average X-ray spectrum with $\Gamma_{\mathrm{Eff}} = 1.2$-$1.4$. Absorption may be commonly present.

A Simple Model for WLQs

We have suggested a “shielding” model for WLQs.

Can explain, in a simple and unified manner, the weak lines, diverse X-ray properties, and other multiwavelength properties.

Relies on anisotropy of ionizing radiation (e.g., Wang et al. 2014).

Small-scale shielding *inside* the BLR:

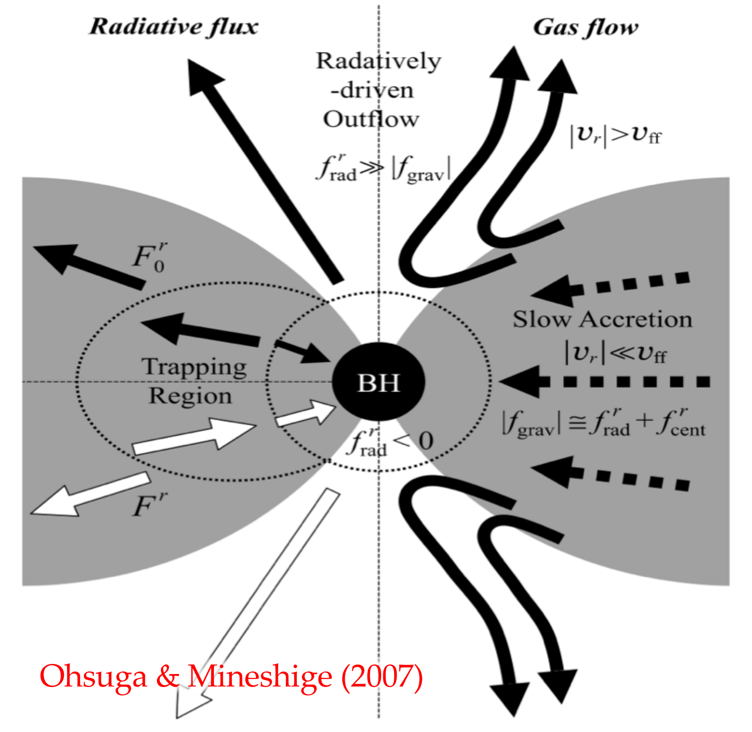
- Prevents ionizing photons from reaching the BLR, explaining the weak lines.
- Causes the X-ray weakness/absorption seen in about half of WLQs, depending upon orientation.

But what is this small-scale shield?

Thick Inner Disk?

A geometrically thick inner accretion disk might serve as the needed small-scale shield.

"Slim" Accretion Disks for High L/L_{Edd}
e.g., Abramowicz et al. (1988)



Ohsuga & Mineshige (2007)

Global MHD Simulation for High L/L_{Edd}
e.g., Jiang et al. (2014); Sadowski et al. (2014)

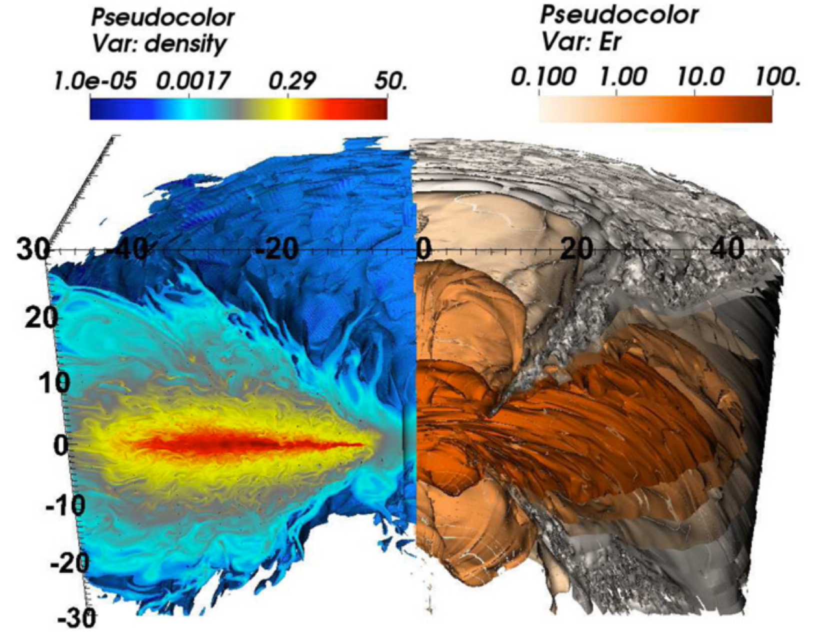
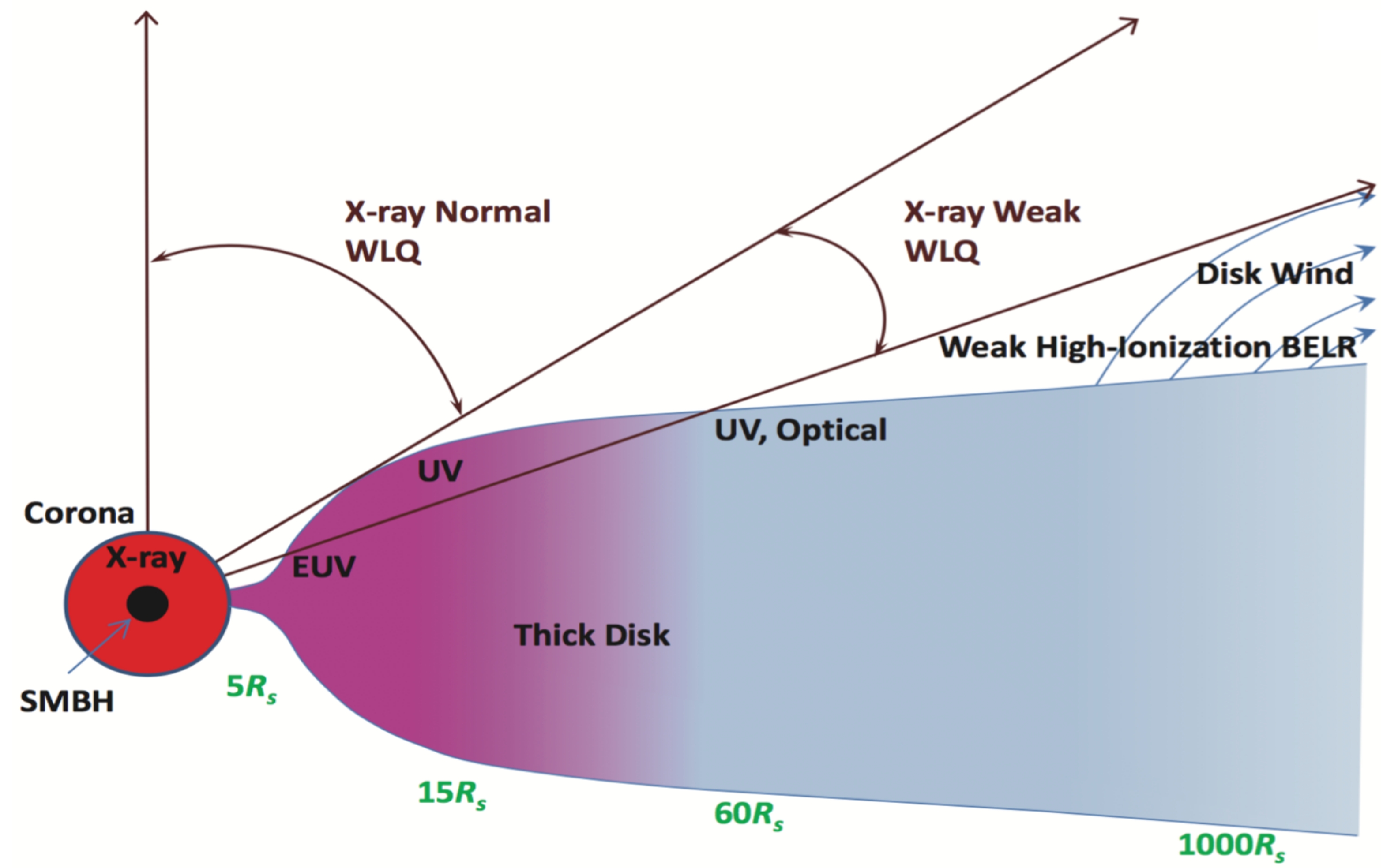


Figure 3. Snapshot of disk structures for density (left) and radiation energy density (right) at time $1.13 \times 10^4 t_s$. Units for ρ and E_r are ρ_0 and $a_r T_0^4$ respectively.

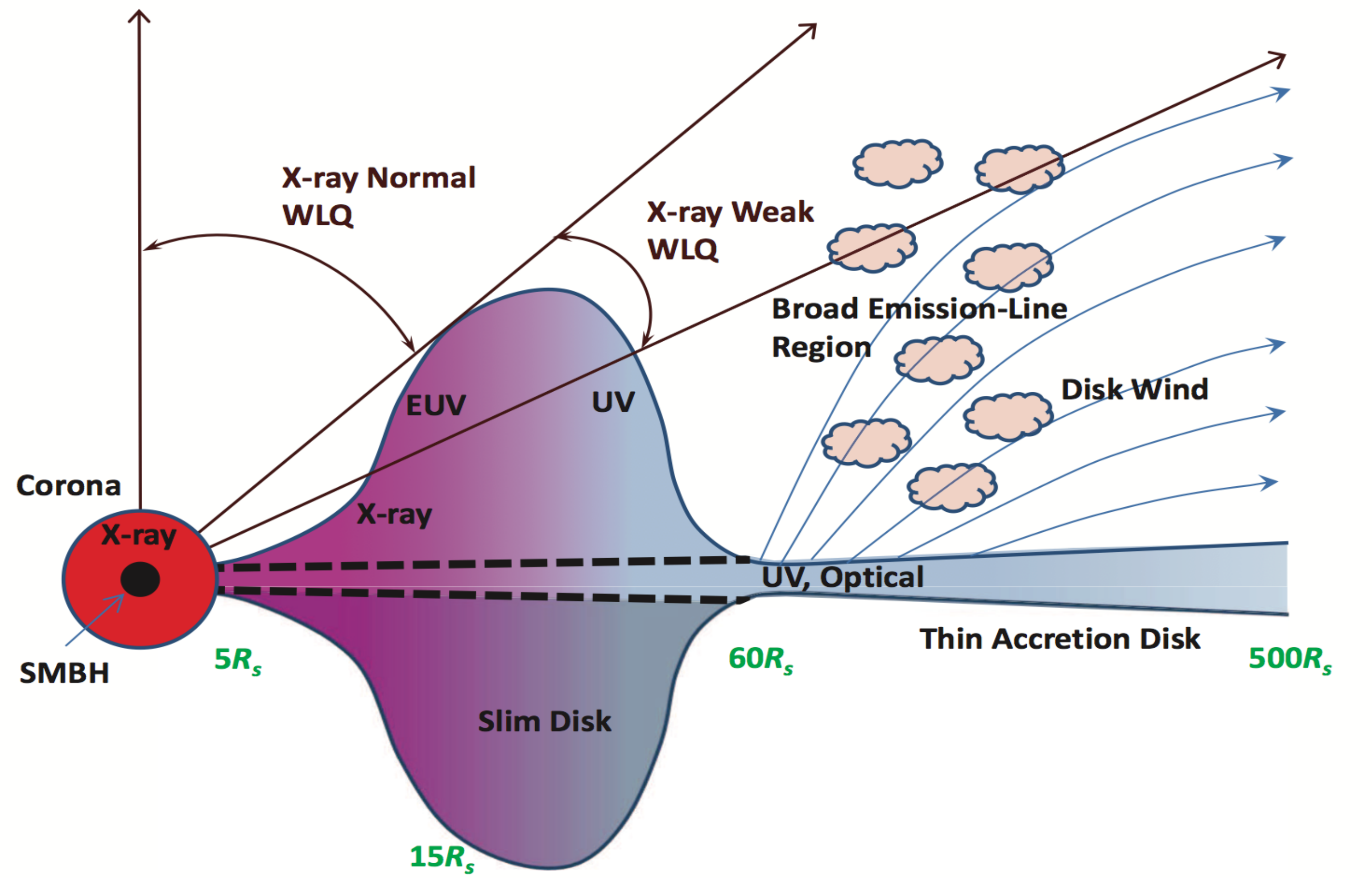
Disk might also thicken due to iron opacity (Jiang et al. 2016).



The (~ equatorial) BLR starved of ionizing photons, independent of orientation.

Presence of X-ray weakness/absorption depends upon orientation, explaining both X-ray weak and X-ray normal WLQs.

Shielding model seems to work well generally, though there could be some intrinsically X-ray weak systems hiding among our sample also.



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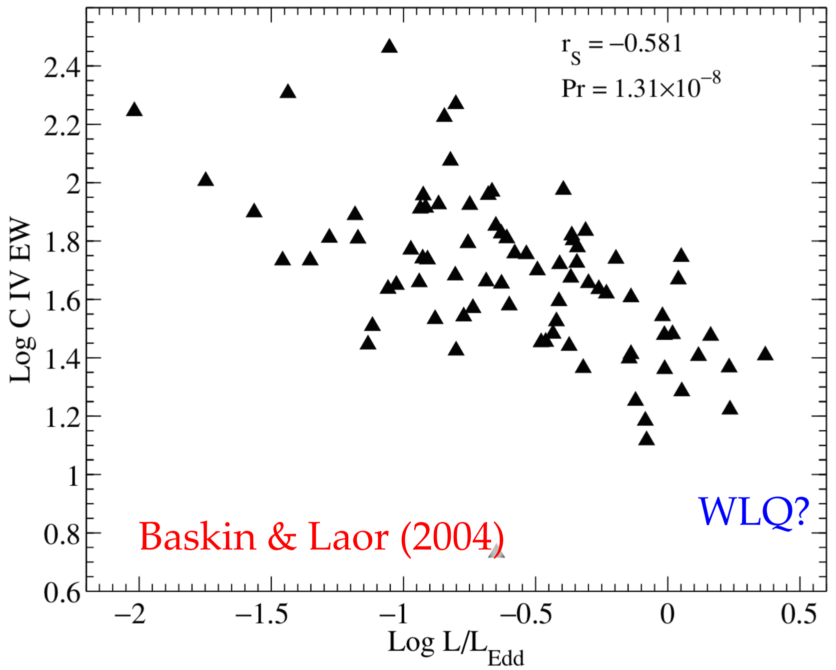
Evidence for High L/L_{Edd}

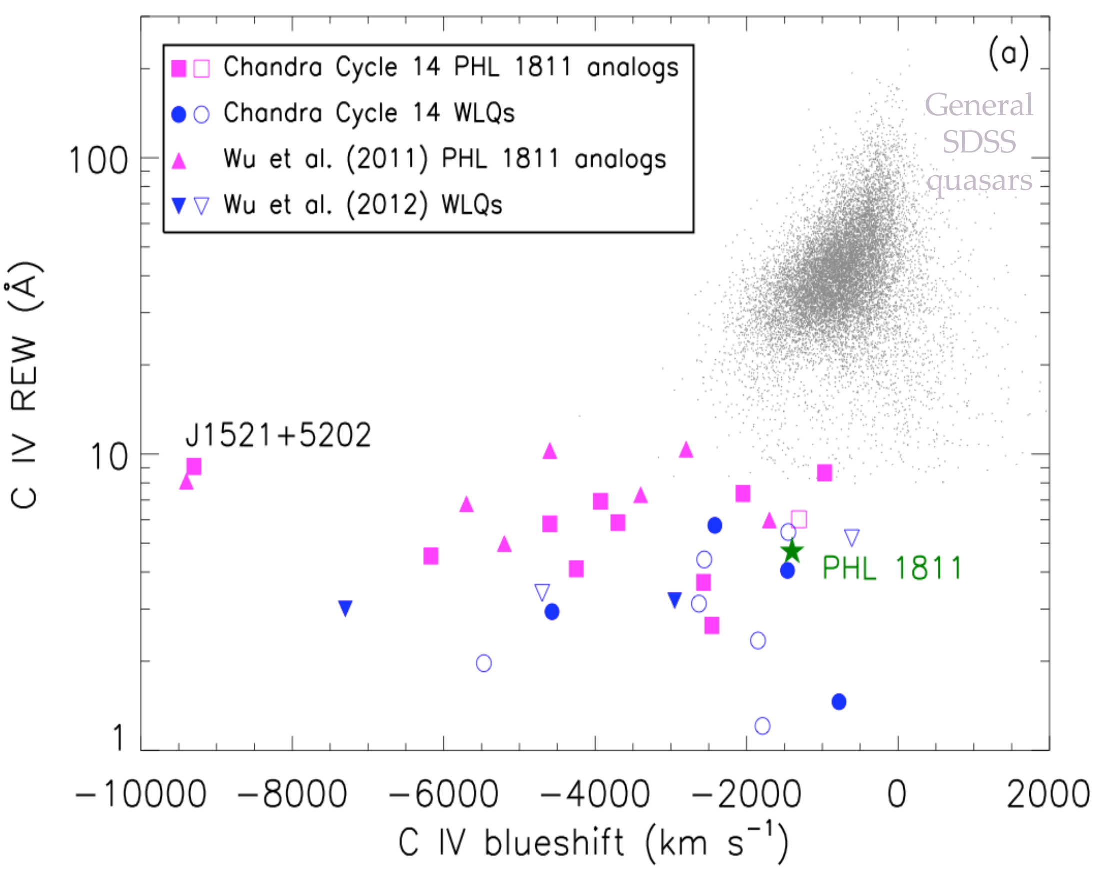
High L/L_{Edd} consistent with the steep power-law X-ray spectra for the X-ray normal/unabsorbed WLQs.

Furthermore, studies of the Baldwin effect find L/L_{Edd} explains C IV better than luminosity.



Virial masses uncertain for these objects with unusual BLRs. But best available estimates using Hβ suggest high L/L_{Edd}. Try reverberation mapping?

Broader Relevance: Shielding and Emission-Line Strengths



Quasars show factor of ~ 100 range in emission-line EWs, for reasons still poorly understood.

Likely effects include anisotropic line/continuum emission, metallicity, BLR geometry.

In terms of emission-line properties, WLQs are extreme but are not disjoint from the overall population.

Seems likely that shielding may be present, at a milder level, in more typical quasars.

Shielding may play broader role in setting strengths of quasar high-ionization lines.

Implications at High Redshift

Gigantic Black Hole Discovered From the Dawn of Time

Astronomers find a cosmic monster that pushes theories of the early universe to the limit.

A giant black hole weighing as much as 12 billion suns was found inside a quasar, a bright astronomical body like the one illustrated here with a black hole at its center.

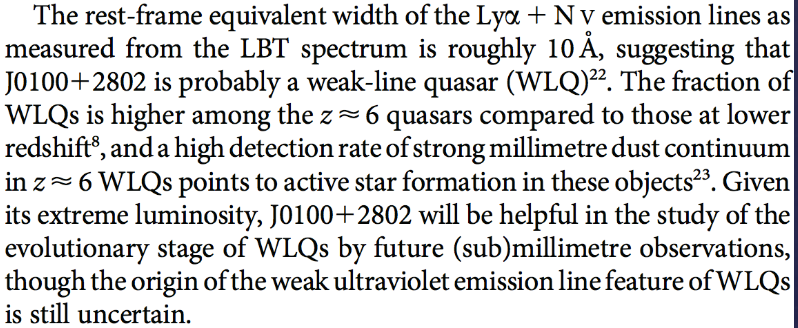
ILLUSTRATION BY ZHAOYU LI, SHANGHAI ASTRONOMICAL OBSERVATORY

By **Michael D. Lemonick**, for National Geographic

PUBLISHED FEBRUARY 25, 2015

Wu et al. (2015)

$z = 6.3$



The rest-frame equivalent width of the Lyα + N v emission lines as measured from the LBT spectrum is roughly 10 Å, suggesting that J0100+2802 is probably a weak-line quasar (WLQ)[22]. The fraction of WLQs is higher among the $z \approx 6$ quasars compared to those at lower redshift[8], and a high detection rate of strong millimetre dust continuum in $z \approx 6$ WLQs points to active star formation in these objects[23]. Given its extreme luminosity, J0100+2802 will be helpful in the study of the evolutionary stage of WLQs by future (sub)millimetre observations, though the origin of the weak ultraviolet emission line feature of WLQs is still uncertain.

Has a Mg II based $M_{\rm Vir} \sim 1.2 \times 10^{10}\ M_\odot$.

Challenge to grow such a massive SMBH.

If WLQs indeed have high $L/L_{\rm Edd}$, helps with the high luminosity and rapid growth.

Also it is a WLQ, for which virial masses are tricky.

Given our comparison of Mg II vs. Hβ masses for WLQs, its mass may be ~ 3+ times lower, making the challenge easier.

Ai et al. (2016) Chandra measurements consistent with X-ray normal WLQs.

More generally, since quasar $L/L_{\rm Edd}$ ratios grow with redshift, should check if the fraction of WLQs grows with redshift.